Science in China Series E: Technological Sciences

© 2009 SCIENCE IN CHINA PRESS
Springer

www.scichina.com
tech.scichina.com
www.springerlink.com

Traditional mortar represented by sticky rice lime mortar——One of the great inventions in ancient China

YANG FuWei, ZHANG BingJian†, PAN ChangChu & ZENG YuYao

Laboratory of Cultural Relics Conservation Materials, Department of Chemistry, Zhejiang University, Hangzhou 310027, China

The development of traditional lime-based bond in ancient times was reviewed in this paper. It was proved by a lot of historical data that the application of organic materials in inorganic mortar was a sharp-cut characteristic during the developing process of construction gelled materials in ancient China. The important role sticky rice mortar ever played and the historical significance were revealed. Due to the excellent performance, such as high adhesive strength, good toughness, water-proof and so on, traditional mortar represented by sticky rice mortar should be one of the greatest technological contributions of the day in the world. Modern technology was employed in the study of the sticky rice lime mortar and the researching results of our laboratory and some researchers, including the composition and the mechanism of solidification, were also presented. It was found that the sticky rice acted as a matrix of bio-mineralization which affected the microstructure of the calcium carbonate crystal and there was cooperation between sticky rice and calcite produced during the solidifying of the sticky rice mortar, which maybe lead to the excellent performance of the mortar. Because of excellent performance and importance in science, sticky rice mortar can be regarded as one of the greatest inventions in construction history of China. Relative research of sticky mortar will be of importance for the exploring of ancient momentous invention and the repairing of ancient construction.

invention, sticky rice lime mortar, lime, bio-mineralization, mechanism

1 The history of development about lime-based gelled materials

In civil engineering, gelled materials are defined as materials which can stick granular material, such as sand and carpolite or massive material, such as stick and stone together, including lime, gypsum, rubber and asphalt[1]. Among these materials, lime-based gelled materials which mainly comprised of lime were most widely used and the roles they played were the most important in the history of architecture.

A long time ago, Chinese began to use lime and lime-based gelled materials. It was shown by archeological evidences that the calcination of lime stone and application of lime started long before prehistoric period[2,3]. By the mid to late West Zhou (1046－771B.C.), lime was broadly used in the reinforcement of pillar base, groundwork and roof[4]. In East Zhou period, lime was used in tomb construction. For example, it was recorded in Zuo Zhuan that "Duke Wen of Song died in the 2nd year of Duke Cheng of Lu (635 B.C.) and clam lime was used in his elaborate tomb[5]". Here, the clam lime referred to lime calcined by clam shell. After Qin & Han dynasties, lime was used more widely. The ground of Xianyang palace site was found to be constructed by pig blood, lime and stone and the surface of it was maroon, smooth and beautiful, having the function of moisture proof and adornment[6]. The express of Empire Qin (221－206 B.C.) was rammed with lime and local loess[7].

Received December 31, 2007; accepted August 18, 2008
doi: 10.1007/s11431-008-0317-0
†Corresponding author (email: zbj@mail.hz.zj.cn)
Supported by the National Natural Science Foundation of China (Grant No. 20671080) and the National Technology Support Program of China (Grant No. 2006BAK30B02)

In the Han dynasty (206B.C.－8A.D.), lime was found frequently used in tomb building, such as wall painting[8−10], wallplaster[11], tomb door sealing[12] and the lime base of coffin[13]. It is worthy pointing out that at least in Han dynasty, inorganic hybrid gelled material called "tabia" (composed of lime, loess and sand) by people was invented and applied[8]. In the Sixteen States and the Empire of the Eastern Tsin Dynasty (317－420A.D.), the use of tabia was more widely. Tomb constructed by tabia was found in the old haunt of North Yan[14]. Tongwan city－the capital of the state Helian was also found to be built with tabia[15]. After seeing the Tongwan city by himself, Shen Kuo, who was a scientist of North Song dynasty, described the city as follows in his book the Dream Rivulet Diary: "Helian city is hard like stone"[16]. Reference of China General History also said the city was "hard enough to sharpen knife and axe"[17]. The toughness of tabia can be seen from these records.

At least no later than South-North Dynasty (386－589A.D.), sticky rice lime mortar was already a full-blown technology[18]. The appearance of organic/inorganic hybrid mortar like sticky rice lime mortar was a great progress in technology of lime-based gelled materials. The building work Tian Gong Kai Wu written in Ming Dynasty recorded in detail the composition, the method of making and performance of it: "sticky rice soup and Actinidia chinensis cane juice is added to the mixture of 1/3 of lime and 2/3 of loess and river sand, well stirred and the mortar is produced. The buildings constructed by it is very strong and permanent and this kind of material is named as tabia"[19]. This kind of tabia added sticky rice soup was the sticky rice lime mortar we mentioned above. The addition of natural organic compounds like sticky rice soup greatly improved the performance of building gelled material. Due to creativity and excellent performance of it, such as high adhesive strength, good toughness and water-proof[20], traditional organic/inorganic hybrid mortar like sticky rice lime mortar was valued by many people after its invention. The book Linji Zazhi written by Jiang Xiufu in Song Dynasty said "it is as hard as stone"[21]. Li Xusheng et al. thought the application of it "immensely improve the stability of buildings"[22]. The results of evaluation showed that the bonding properties of it were good enough to match modern cement[23,24]. Besides sticky rice soup, juice of vegetables like star fruit cane, the leaf of Polggonumhydropiper and Bletilla striata, egg white and animal blood were ever used in traditional mortar[19]. Putty made of tung oil, fish oil and lime was also applied in buildings, timber component and ship-building long ago[19]. Owing to space limitation, the study of these materials will be published in another paper.

The history of application of lime in Europe was very long too. In ancient Greek (330B.C.－30A.D.), lime made from lime stone was used as construction mortar. In Roman times, hybrid material of lime-sand[25] and lime-gypsium[26] were employed in building. Later, lime-sand bi-component mortar was improved by introducing ground volcanic ash or ground brick and ceramic chip[27−29] when volcanic ash was not available. In comparison, this tri-component lime-hydraulic constituent-sand mortar had better strength and waterproofness than bi-component lime-sand mortar. This tri-component lime-hydraulic constituent-sand mortar was called as Roman mortar[30] later. The property of Roman mortar was similar to inorganic tabia in ancient China. Until the appearance of modern cement, Roman mortar was the best mortar used in Europe.

In short, mortars used in ancient Europe were purely inorganic ones; however, sticky rice lime mortar invented in ancient China was a kind of organic/inorganic hybrid mortar. This kind of organic/inorganic hybrid mortar was better than pure inorganic ones in bonding property, toughness and waterproofness. Because of the invention of organic/inorganic hybrid materials like the sticky rice mortar, China ever took over the lead in the technology of building gelled materials. Dr. Joseph Needham, the famous scientist and historian from Britain, thought highly of these kinds of ancient inventions in China[31]. As an invention in ancient China, introducing organic materials in inorganic gelled materials was unique and was very worthy in the advance of building mortar.

2 The role sticky rice mortar played in the building history of ancient China

Due to good strength, toughness and waterproofness, sticky rice mortar was used widely. From the archeology evidences, sticky rice mortar was found mainly in tombs, city constructions and water resource facilities. Earlier in South-North Dynasty, it was used in tomb building, for example, the brick tomb in Deng county, Henan

province[18]. From Song Dynasty to Qing Dynasty, sticky rice mortar was more widely used in the construction of tomb and this kind of tomb was specially named as "lime compartment"[32−37]. It was recorded that the building material of "lime compartment" was sticky, airtight and "hard like stone"[21]. In 1978, the tomb of Xu Pu and his wife in Ming Dynasty was found. This tomb built with sticky rice mortar was so firm that bulldozer could do nothing about it and drill robs and shovels were damaged when unearthing it. In city wall and temple construction, sticky rice was also involved. The tower of Guoqing temple built in Sui Dynasty and rebuilt in Song Dynasties[38] and the stone tower with sutra inscriptions in Kaiyuan temple built in Tang Dynasty[22] both used sticky rice lime mortar and are still firm today. Those ancient towers, temples and bridges in Quan County built in Tang or Song Dynasties even survived the 7.5 grade earthquake of 1604. The Yuquan iron tower in Dangyang, Hubei was built in North Song, its stone base was stock together with sticky rice mortar[39]. Sticky rice component was also found in the towers of Shaolin temple built in Song & Ming Dynasties[40]. Fahua tower in Jiading district of Shanghai was built in Yuan Dynasty and sticky rice mortar was found between the bricks of the tower base[41]. There was a 300 y old stone tower built in Qing Dynasty in Baohe town, Rongchang county, Chongqing. Although leaned about 45°, this 10-meter tower built with sticky rice lime mortar still stands tall and upright. The toughness of sticky rice was proved better than cement[42]. In 1920's and1980's, city wall and base built in Tang Dynasty was found by archeologist. The city wall and base were constructed by bricks and sticky rice mortar[43]. The city wall of ancient Haizhou city in Dalian was built in Song Dynasty and the building materials comprised of sticky rice too[44]. Several ancient buildings of Ming Dynasty, for example, the city wall of Ming Dynasty in Nanjing[45], the city gate of Guide ancient city in Shangqiu, Henan[46] and the city wall of Jingzhou[47] were all constructed by sticky rice mortar. Owe to its waterproof property, sticky rice mortar was also used in water resource facilities. The bank of Shaogong and city wall of royal tomb of Ming Dynasty[48], the bank of Qiantang river[49] and the bank of Lugou bridge[50] were all built with sticky rice mortar and were still in good shape today. Sticky rice was also employed to build stone bridge. These kinds of bridges included Shanben bridge of Ming Dynasty in Jiangsu province[51], South bridge of Yuan Dynasty in Wuhan[52], Sanyuan dragon bridge of Yuan Dynasty in Shanxi province[53] and Safeguard bridge in Yunnan province[54]. Until modern times, sticky rice was still in use, for example, Kaiping turrent[55] in Guangdong province and soil enclose storied buildings in southwest of Fujan province[56].

Sticky rice lime mortar was a wonderful lime-based gelled material in ancient China even in the history of world construction. It can be regarded as one of the great inventions of ancient China. However, this excellent material was ignored by most of us. The importance of it was covered up by other building materials and technology, such as fired brick and tile, tenon-and-mortise work and carved beams and painted rafters and so on for a long time in the past. Obviously, without mortars like sticky rice lime mortar, it is very difficult for the beautiful ancient buildings to survive. Completely depending on modern chemical bonding material like cement rather than traditional bonding like sticky rice lime mortar will be harmful for the protecting and repairing of ancient buildings.

3 The scientific study of sticky rice mortar

Sticky rice mortar invented at least 1500 y ago (dated from South-North Dynasty) was ever widely used in ancient times for its excellent properties including good adhesive strength, toughness and waterproofness. Just for its good properties, sticky rice lime mortar attracted the attention of antiquarian gradually and was studied by the researchers of Chonggong University and Zhejiang University.

Chen Junliang[40] carried out iodine-starch experiment for the mortar samples from several towers of Song & Ming Dynasties and the results showed there was sticky rice component in them. FTIR, TGA-DSC and iodine-starch experiment were employed in the study of ancient city wall samples of Ming Dynasty from Xi'an and Nanjing. Samples of Qing Dynasty from a memorial arch of Shaoxing, Zhejiang were analyzed too. The results also indicated there was sticky rice component in them[57,58]. All these analysis results were consistent with the ancient building work.

The FTIR results of the sticky rice (Figure 1a), the mortar sample of Ming Dynasty from Xi'an (Figure 1b), and calcite (Figure 1c) are given in Figure 1. The

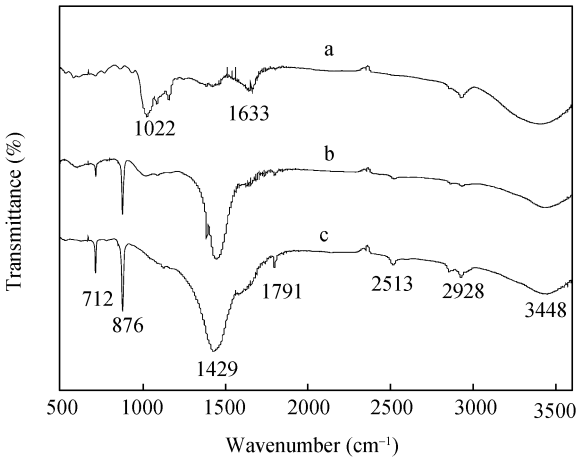

Figure 1 FT-IR spectra of three samples[58]. a, Sticky rice; b, mortar sample of Ming dynasty from xi'an; c, calcite.

absorbance bands at 712, 876, 1429, 1794 and 2513 cm^{-1} are assigned to the calcite. In addition, the adsorption bands between 1000 and 1100 cm^{-1} are from the sticky rice. By contrast of Figure 1a, Figure 1b and Figure 1c, it can be concluded that the inorganic component of the mortar sample of Ming Dynasty from Xi'an mainly consists of calcite, and the organic components might contain part of the sticky rice undecomposed.

The results of TGA-DSC of mortar sample of Ming Dynasty from Xi'an are shown in Figure 2. From the curve of TGA, the weight loss of mortar sample in the temperature range of 200—600℃ and 630—800℃ are 10% and 30% respectively.

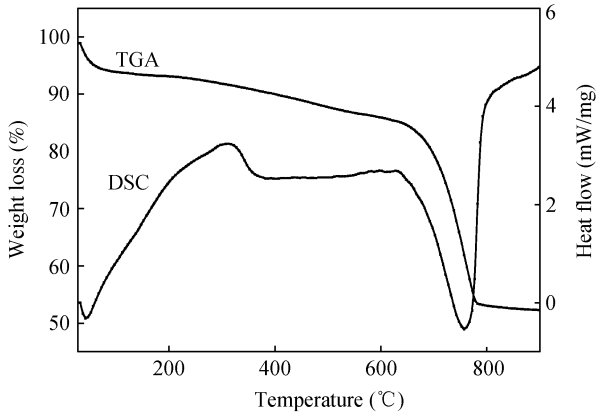

Figure 2 DSC-TGA spectra of mortar sample of Ming dynasty from Xi'an[58].

In the curve of DSC, there are an exothermic peak at around 350℃ and an endothermic peak at about 760℃. The endothermic peak at about 760℃ can be assigned to the decomposition reaction of calcite and the exothermic peak at around 350℃ can be assigned to the combustion reaction of organic material. These results confirm with the results of FTIR each other perfectly.

The color develop reaction of starch with iodine is sensitive and selective. The reaction of iodine with amylose produces blue complex, while the reaction of iodine with amylopectin produces violet one. The results of iodine-starch reaction (Figure 3) show that the organic component in mortar sample should be amylopection. Because the mainly component of sticky rice is amylopectin, the conclusion that there is sticky rice in the mortar samples is persuasive. The same experiments was done with the mortar samples of memorial arch of Qing Dynasty and the results indicated there was sticky rice component in the mortar too.

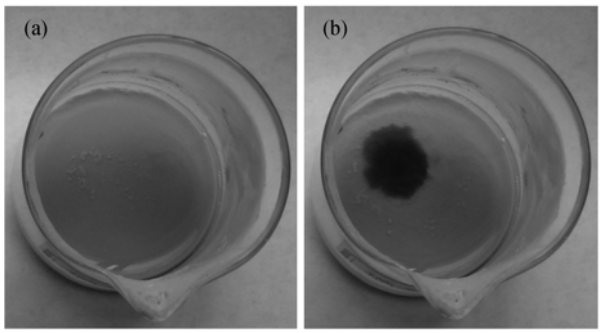

Figure 3 Iodine-starch experiment of mortar sample of Ming dynasty from xi'an[58]. (a) Iodine reagent free; (b) Iodine reagent.

But, how could the sticky rice survive after thousands and hundreds of years? This may attribute to the special fabrication technology and the solidification process of sticky rice mortar. In the manufacturing operation, some chemical reactions involve lime occur:

$$CaO+H_2O = Ca(OH)_2 \quad (1)$$

$$Ca(OH)_2 \rightarrow Ca^{2+}+2OH^- \quad (2)$$

In reaction (1), quick lime is turned into lime and a lot of heat is produced. Because of high temperature, there is active oxygen released and the active oxygen released can kill bacteria[59].

Strong base environment generated by reaction (2) can strain even kill bacteria by destroy the cell membrane of bacteria, which was verified by experiment[60]. The pH of $Ca(OH)_2$ is about 12.4 and almost no bacteria can survive in it.

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O \quad (3)$$

In reaction (3), lime is turned into calcium carbonate gradually in air and the strength of sticky rice mortar

will increase slowly, until lime is consumed totally. But the complete transformation of lime will take a very long time because of diffusion limitation of CO_2. The base environment retained by reaction (2) makes sticky rice free from bacteria and survive.

Further study showed that the key components of the sticky rice lime mortar for cementation were lime and sticky rice. Soil and sand were inert for sticky rice and they were just filling material in the mortar[61].

But what is the function of sticky rice in the mortar? It was found by our research[61−63] that sticky rice could increase the pressive strength by 30 times, surface toughness by 2.5 times and waterproofness to 80 d. Further investigation showed that sticky rice played at least two important roles as follow.

1) Sticky rice can control reaction (3)[61]. Polysaccharide like sticky rice can affect the biomineraliztion process of carbonate and change the size, shape and structure of carbonate crystals. Hskon, Cyclodextrin and modified starch were found could change the shape and host lattice of calcium carbonate by Yanglin[64], Zhang Xiuying[65] and Ding Weijia[66] et al. respectively. The effect of sticky rice on the carbonation process of lime was investigated by us[57]. It was found that the nano-size calcite was produced and the structure was more compact after the introduction of sticky rice. This kind of compacting structure should be the basis of the good property of sticky rice lime mortar, such as high pressive strength and surface toughness.

2) There is cooperation between sticky rice and calcite[57,61], that is, they wrap and pad each other, which can be seen from the SEM of samples (Figure 4). These kinds of fine structure make sticky rice mortar strong and flexible. Similar organic/inorganic structure appears frequently in the products of the biomineralization such as bone, tooth and shell of mollusk[67]. The bone and tooth of human and animals are hybrid material of collagen and hydroxylapitite[68]; the shell of mollusk is hybrid material of amylase, protein and calcium carbonate[69].

In short, we believe that the solidification process of sticky rice mortar is natural polysaccharides like sticky rice involved biomineralization. In the process, the crystalization and microstructure of calcite are controlled by sticky rice, calcite produced integrates with sticky rice and a compacting hybrid structure with excellent mechanical properties is formed.

4 Results

It was proved by a lot of historical data that the traditional gelled materials like sticky rice lime mortar used at least 1500 y ago was indeed a great invention of ancient China. The reason why the sticky rice lime mortar with good properties such as high adhesive strength, good toughness, water-proof and so on lies on the biomineralization microstructure and the integration between organic sticky rice membrane and inorganic nano-size calcite grains. Thanks to the invention and wide use, the stability and constancy are greatly improved and many ancient buildings can survive hundreds and even thousands of years. From the point of technology history, organic/inorganic hybrid gelled materials first appeared in ancient China. Chinese people could skillfully utilize the rule of biomineralization and cooperation of organic/inorganic a long time ago. The wisdom of ancient Chinese thousands years ago was marvelous. Now, the scientific study about traditional building materials like sticky rice lime mortar was of importance for carrying forward Chinese culture, scientific utilization of traditional technology and repairing or protection of ancient buildings.

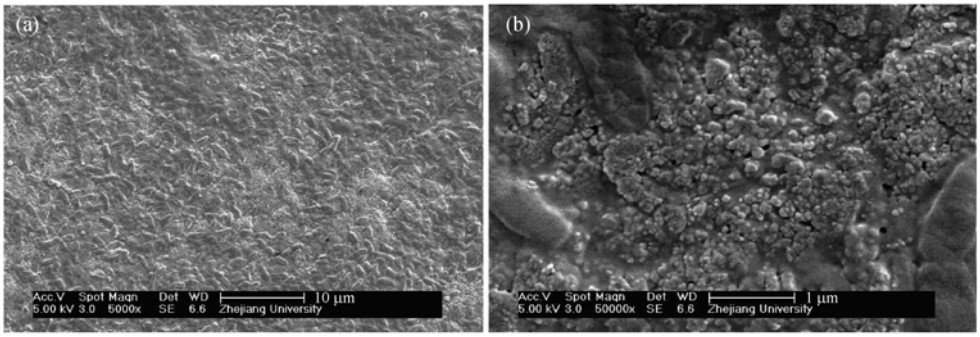
(a)
Acc.V Spot Magn Det WD 10 μm
5.00 kV 3.0 5000x SE 6.6 Zhejiang University
(b)
Acc.V Spot Magn Det WD 1 μm
5.00 kV 3.0 50000x SE 6.6 Zhejiang University

Figure 4 SEM image of sticky rice lime-mortar (volume ratio of 0.01 M $Ca(OH)_2$ with 3% sticky rice solution is 1:1)[61]. (a) 5000*x*; (b) 50000*x*.

1 Liu J Z. Civil Engineering Materials (in Chinese). Beijing: Science Press, 2005. 37
2 Lu L C. Discussion about the properties of "lime powder" in the new stone age. In: the Institute for the History of Natural Science Eds. Collection of Science and Technology History (in Chinese). Shanghai: Shanghai Scientific and Technical Publishers, 1985. 14: 107
3 Qiu S H. When did the lime production begin? The ^{14}C isotopic geochemical method can answer the question (in Chinese). Archeol Cul Rel, 1980, 5: 126－130
4 Yao Y. The History of Xi'an in Han Dynasty (Science and Technology) (in Chinese). Xi'an: Shanxi People's Publishing House, 1993. 477－478
5 Zuo Q M (Spring and Autumn Period). Zuo Zhuan (in Chinese). Changsha: Yuelu Press, 2001. 289
6 Xing J W. Shanxi Ancient Science and Technology (in Chinese). Beijing: China Science &Technology Press, 1995. 161－163
7 Wang K. The Ancient History of Road Transportation in Shanxi (in Chinese). Beijing: China Communication Press, 1989. 10
8 Tie F D. Conservation and restoration of wall paintings of early Western Han Dynasty (1)－Investigation of conservation history and actuality (in Chinese). Sci Conserv Archaeol, 2004, 16 (1): 47－51
9 Huang Y F. Fresco Art of a Han tomb in Henan province (in Chinese). Acad Forum Nandu, 1998, 18 (2): 17－20
10 Ma X Y. A different opinion about Fresco of the Dahuting Han tomb (in Chinese). J Hist Sci, 1999, 5: 32－65
11 Shanxi Archeology Research Institute. Brief Excavation Report of the Northern Dynasty Tomb Found in the Northern Suburbs, Xi'an (in Chinese). Archaeol Cul Rel, 2005, 1: 7－16
12 CPAM of Zoucheng City. Excavation of Liu Bao's Tomb of the Western Jin at Zoucheng in Shandong (in Chinese). Cul Rel, 2005, 1: 4－26
13 Shanxi Provincial Institute of Archeology. Remains of Zhou Dynasty and Han Dynasty were found in Lingshi country, Shanxi (in Chinese). Cul Rel, 2004, 8: 29－37
14 Pu S. North Yan tomb in Yuantaizi village, Chaoyang county, Liaoning province (in Chinese). Cul Rel, 1994, 11: 43－47
15 Yao Q Z, Lv Da. On historical evolution of the ancient Tongwan City & its architecture (in Chinese). J Yan'an Univ (Social Science Edition), 2004, 26 (2): 126－128
16 Shen Kuo (Song Dynasty). The Dream Rivulet Diary (in Chinese). Changchun: Times Wenyi Press, 2001. 110
17 Tang C R. References of Chinese General History (in Chinese). Beijing: Zhong Hua Press, 1983.
18 Archeology crew of Henan province. A Stick Tomb with Colorized Portrait in Deng Country, Henan Provice (in Chinese). Beijing: Cultural Relic Press, 1958.
19 Song Ying-xing (Ming Dynasty). Tian Gong Kai Wu (in Chinese). Shanghai: Commercial press, 1958. 197.
20 Wu Q Z. The experience and implication for the flooding control in the ancient towns in China (continued) (in Chinese). City Plan Rev, 2002, 26 (5): 76－84
21 Jiang X F (Song Dynasty). Linji Zazhi, About City, Volume 30 (in Chinese). Shanghai: Shanghai Ancient Books Publishing Company, 1988
22 Li X H, De Q S. The artistic appreciation of stone tower with sutra inscriptions (in Chinese). Architect Gard, 2005, 3: 32－34
23 Lin J S, Lin Z J, Chen J F. The ancient great earthquake and earthquake-resistance of the ancient buildings (towers, temples and bridges) in Quanzhou city (in Chinese). World Earthquake Eng, 2005, 21 (2): 159－166
24 Ji S J. Some discussions about Nanjing city wall (in Chinese). Palace Mus J, 1984, 2: 70－81
25 Riccardia M P, Duminucob P, Tomasic C, et al. Thermal, microscopic and X-raydiffraction studieson some ancient mortars. Thermochim Acta, 1998, 321: 207－214
26 Paulo M d S, Veiga M d R, de Brito j. Gypsum coatings in ancient buildings. Constr Build Mater, 2007, 21: 126－131
27 Hasan B, Sedat A, Başak I, et al. Characteristics of brick used as aggregate in historic brick-lime mortars and plasters. Cem Concr Res, 2006, 36: 1115－1122
28 Moropoulou A, Bakolas A, Anagnostopoulou S. Composite materials in ancient structures. Cem Concr Compos, 2005, 27: 295－300
29 Bakolas A, Biscontin G, Contardi V, et al. Thermoanalytical research on traditional mortars in Venice. Thermochim Acta, 1995, 269: 817－828
30 Güleç A, Tulun T. Physico-chemical and petrographical studies of old motars and plasters of Anatolia. Cem Concr Res, 1997, 27(2): 227－234
31 Needham J. Science and Civilization in China. Shanghai: Shanghai People's Publishing House, 2001. 2
32 Jiangsu Committee for the Protection of Antiquities and Monuments. Fresco tomb of Song Dynasty in Huai'an, Jiangsu (in Chinese). Ref Mater Cul Rel, 1960, 8 (9): 43
33 Institute of Cultural Relics of Hebei. The report on archaeological excavations of the Shi relative's grave site in Hebei province. In: The Collection of Archeology Discovery in Hebei Province (in Chinese). Beijing: Orient Press, 1998. 344－369
34 Liu X D. The earth pit tomb with stone out coffin in Jin Dynasty and relative problems. In: The Collection of Archeology Discovery for the 20th Anniversary of Archaeology Department, Jilin University (in Chinese). Beijing: World Affairs Press, 1993, 397－401
35 Yang G L.Viewing the Remains-antirot technique in the ancient grave custom (in Chinese). J Changsha Soc Work Coll, 2004, 4: 11－15
36 Ma J. A surprising discovery: A ranee tomb was found in East China Jiao Tong University (in Chinese). Rel S, 2003, 3: 116－117
37 De'an Museum. A briefing about the material collection of Daixiogshi tomb in De'an (in Chinese). Rel S , 1994, 4: 5－9
38 Zheng Q. On architectural features and humanistic values of the ancient pagodas in Taizhou (in Chinese). Huazhong Architect, 2003, 21: 83－86
39 The Archeological Team at the Yuquan Iron Pagoda. Clearing up of the basement of the Yuquan Iron Pagoda at Dangyang, Hubei, the archeological team at the Yuquan iron pagoda (in Chinese). Cul Rel, 1996, 10: 43－57

40 Chen J L. The Researching About the Relation of Materials Prescription of Ancient Mortar and Strength (in Chinese). Tainan: National Cheng Kung University, 2004
41 CPAM of Shanghai City. Excavation of the Yuan and Ming underground closets of the Fahua Pagoda at Jiading, Shanghai (in Chinese). Cul Rel, 1999, 2: 4－15
42 Qiu Z J. The Chongqing "leaning tower pisa" with a tilt angle of 45 degree suvived 300 hundreds of years (in Chinese). Buil'Mon, 2006, 7: 55－55
43 Peng S F. Rethinking of the change and development of ancient Nanchang city (in Chinese). Rel S, 1995, 4: 86－98
44 Zhang Y H. The History of Building Technology in Ancient China (in Chinese). Beijing: Science Press, 1985. 173
45 Wu Q Z. Study on citywall and moat military defence system of Nanjing City in Ming Dynasty (in Chinese). Architect, 2005, 2: 96－101
46 Zhao T M. Features the gate of Guidefu ancient city in Shangqiu (in Chinese). Shanxi Architect, 2007, 33 (6): 63－65
47 Wang X S, Fixing up and application technology of ancient city wall (in Chinese). Trad Chin Architect Gard, 2004, 1: 20－22
48 Wang Z C. Ancient city below water－Sizhou city (in Chinese). Encyclopedic Knowl, 2005, 11: 54－56
49 Yu H Y, Chen D. Protection and development of tourism resources for ancient seawall of Qiantang River (in Chinese). Zhejiang Hydrotechn, 2004, 4: 9－10
50 Wang Y M. The Developing History of Cement in China (in Chinese). Beijing: China Architecture & Building Press, 2005. 4－5
51 Cai S C. Introduction of ancient bridges in Jiangsu province (in Chinese). Trad Chin Architect Gard, 2001, 3: 48－54
52 Wuhan City Museum. Ancient bridge in Wuhan (in Chinese). Wuhan Cul Historical Mater, 2001, 9: 45－48
53 Lu X. The history of dragon bridge (in Chinese). Rel Museol, 2007, 2: 56－57
54 Wang W J. Checking, assessing, repairing and reinforcing design of Huguo Bridge, Kunming City (in Chinese). Yunnan Commun Sci Tech, 2001, 2: 44－48
55 Shen X Y, Liu P L, Liu A. Type, value and heritage management model of Diao Tower in Kai Ping (in Chinese). J Hunan U Arts Sci (Social Science Edition), 2006, 1(4): 95－99
56 Cai J S. Environment friendly Castle-Like Dwellings (in Chinese). Architect J, 1995, 5: 42－44
57 Zeng Y Y, Zhang B J, Liang X L. A case study and mechanism investigation of typical mortars used on ancient architecture in China. Thermochim Acta, 2008, 473 (1-2): 1－6
58 Yang F W, Zhang B J, Zeng Y Y, et al. The exploring research of the scientificalness and application of traditional sticky rice mortar. Palace Mus J, 2008, 5: 105-114
59 Sawai J, Shiga H, Kojima H, et al. Kinetic analysis of the bactericidal action of heated scallop-shell powder. Int J Food Microbiol, 2001, 71: 211－218
60 Catalano V R, Knabel S J. Incidence of Salmonella in Pennsylvania egg processing plants and destruction by high pH. J Food Prot, 1994, 57: 587－591
61 Liu Q, Zhang B J. Bioinspired preparation of a protective Biomineralized material on the surfaces of historic stones. Acta Chim Sinica, 2006, 64 (15): 1601－1605
62 Liu Q, Zhang B J. Syntheses of a novel nanomaterial for conservation of historic stones inspired by nature. Mater Lett, 2007, 61: 4976－4979
63 Zeng Y Y, Zhang B J, Liang X L. A study on the Characteristics and consolidating mechanism of Chinese traditional mortars used on historical architecture. Sci Conserv Archaeol, 2008, 20 (2): 1－7
64 Yang L, Ding W J, An Y G, et al. Control synthesis of Aragonite Calcium Carbonate with Glucan as the template. Chem J Chin Univ, 2004, 8: 1403－1406
65 Zhang X Y, Liao Z J, Yang L, et al. Interaction between β-Cyclodextrin and Crystallization of Calcium Carbonate (in Chinese). Acta Chim Sinica, 2003, 1: 69－73
66 Ding W J, An Y G, Yang L, et al. Study on IR of interaction of three Modified-Starchs and Crystallization of Calcium Carbonate (in Chinese). Spectrosc Spect Anal, 2005, 25 (5): 701－704
67 Wang L D, Sun W Z, Liang T X, et al. Research status of Biomimetic materials (in Chinese). J Mater Eng, 1996, 2: 3－5
68 Xie F L. Cross-linkage of hydroxyapatite/gelatin nanocomposite using EGDE (in Chinese). Sci Tech Gel, 2007, 27 (1): 24－28
69 Li X H, Hou W T. The conch structure and Biomimetic research on ceramics (in Chinese). Bull Chin Ceram Soc, 2003, 2: 53－55